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(54) **Organic thin film transistor with enhanced carrier mobility**

(57) An organic thin film transistor including a gate (21, 31, 41, 51, 61, 71) on a layer of gate insulator material (22, 32, 42, 52, 62, 72), a source (25, 35, 45, 55, 65, 75) and a drain (26, 36, 46, 56, 66, 76) positioned in spaced apart relationship on a film (24, 34, 44, 54, 64, 74) of organic semiconductor material with uniaxially aligned molecules, the film (24, 34, 44, 54, 64, 74) of organic semiconductor material being positioned so that the molecules are aligned between the source (25, 35, 45, 55, 65, 75) and drain (26, 36, 46, 56, 66, 76) in a direction from the source (25, 35, 45, 55, 65, 75) to the drain (26, 36, 46, 56, 66, 76), and an orientation film (23, 32, 43, 52, 63, 73) positioned adjacent the film (24, 34, 44, 54, 64, 74) of organic semiconductor material so that molecular uniaxial alignment of the film (24, 34, 44, 54, 64, 74) of organic semiconductor material is achieved by the orientation film (23, 32, 43, 52, 63, 73).

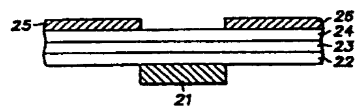

FIG. 2
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are selected from a variety of organic materials including polyimides, perfluoropolymers, liquid crystal polymers, etc. The thickness of the orientation films is in a range from 20 Å to 10 micron, and preferably less than 1000 Å in these specific embodiments.

Methods to achieve highly oriented thin films (i.e., films with molecules generally oriented in a direction parallel to the plane of the film) are known in the art. For example, in liquid crystal panel fabrication, a highly oriented polyimide thin film is obtained by rubbing the surface of the polymer coated substrate lightly in a single direction with a cotton cloth. Ueda and coworker (Y. Ueda, Jpn. J. *Appl. Phys.* 34, 3876 (1995)) have also disclosed a method to attain highly oriented polytetrafluoroethylene thin films by rubbing mechanically. Also, a film of a liquid crystal polymer can be oriented by an electric or magnetic field pulling at temperature close to its glass transition temperature. The film maintains its orientation after it has been cooled to room temperature under the pulling electric or magnetic field. Akiyama et al. (US Patent 5,468,519, entitled "Method for Forming an Orientation Film Including Coupling an Organic Compound to a Silane Coupling Agent in a Magnetic or Electrical Field", issued November 21, 1995) also disclosed a method for forming an orientation film including coupling an organic compound to a silane coupling agent in a magnetic or electric field.

In the specific embodiments disclosed, the orientation film acts as a foundation or seed for the organic semiconductor layer to grow or deposit uniaxially. The orientation direction of the orientation film should be arranged so that the film of organic semiconductor material aligned on the orientation film has the highest mobility in the source to drain electrode direction.

More specifically, as an example, if a film of an organic polymeric semiconductor material with linear extended π-conjugated backbone is used in the transistor, the orientation direction of the orientation film is preferentially controlled such that the film of organic polymeric semiconductor material grows or deposits on top of the orientation film with extended π-conjugated backbone aligned in the source to the drain electrode direction. In another example, if a film of an organic molecular semiconductor material with localized π-conjugation systems is used, the orientation direction of the orientation film is preferentially controlled such that the film of organic molecular semiconductor material grows or deposits on top of the orientation film with the molecule stacking with π-electron overlapping aligned in the source to the drain electrode direction.

Thin films (i.e., layers 24, 34, 44, 54, 64, 74) of organic polymeric semiconductor materials used in this embodiment include but are not limited to: conjugated hydrocarbon polymers such as polyacetylene, polydiacetylene, polyacene, polyphenylene, poly(phenylene vinylene), and the derivatives including oligomers of those conjugated hydrocarbon polymers; conjugated heterocyclic polymers such as polyaniline, polythiophene, polypyrrole, polyfuran, polypyridine, poly(thienylene vinylene) and alike, and the derivatives including oligomers of those conjugated heterocyclic polymers. Also, thin films of organic molecular semiconductor materials used in this embodiment include but are not limited to: condensed aromatic hydrocarbons such as tetracene, chrysene, pentacene, pyrene, perylene, coronene, and the derivatives of those condensed aromatic hydrocarbons; metal complexes of porphine and phthalocyanine type of compounds such as zinc 1,10,15,20-tetraphenyl-21 H, 23 H-porphine, copper phthalocyanine, lutetium bisphthalocyanine, aluminum phthalocyanine chloride.

A substrate (not shown) may be utilized which comprises any of a variety of materials including: inorganic materials such as silicon, ceramic, glass and organic plastic materials such as poly(vinylene chloride)s, polyolefins may be used to support the embodied organic TFT. However, the present invention is particularly useful for organic plastic substrates, where polycrystalline and amorphous silicon TFTs can not normally be fabricated, since the temperature required to process the embodied organic TFTs is generally less then 200 °C..

Thus, a variety of organic TFTs have been disclosed with enhanced carrier mobility. The TFTs are relatively simple and inexpensive to fabricate, with only one additional layer, in some embodiments and no additional layers in other embodiments. It is an intention of this invention to provide an organic TFT with improved carrier mobility on plastic substrate for flexible, lightweight, large-area, display applications

While we have shown and described specific embodiments of the present invention, further modifications and improvements will occur to those skilled in the art. We desire it to be understood, therefore, that this invention is not limited to the particular forms shown and we intend in the appended claims to cover all modifications that do not depart from the spirit and scope of this invention.

Claims

1. An organic thin film transistor comprising:

   a gate electrode (21, 31, 41, 51, 61, 71) positioned on a layer of gate insulator material (22, 32, 42, 52, 62, 72);
   a source electrode (25, 35, 45, 55, 65, 75) and a drain (26, 36, 46, 56, 66, 76) electrode positioned in spaced apart relationship on a film (24, 34, 44, 54, 64, 74) of organic semiconductor material with uniaxially aligned molecules, the film (24, 34, 44, 54, 64, 74) of organic semiconductor material being positioned so that the uniaxially aligned molecules are aligned between the source (25, 35, 45, 55, 65, 75) and drain (26, 36, 46, 56, 66, 76) electrodes in a direction from the source (25, 35, 45, 55, 65, 75) to the drain (26, 36, 46, 56, 66, 76) electrodes, the layer of gate insulator material (22,

encountered in the organic semiconductor films. One obvious way to overcome the problem is to make use of organic semiconductors with higher carrier mobility. This approach requires the tedious work of sieving through hundreds of known organic semiconductors, including labor-intensive designing, and inventing new organic semiconductors with higher carrier mobility.

In the prior art (e.g. TFT 10), the organic semiconductor molecules are randomly oriented in the as-formed organic semiconductor film 13. The carrier mobility is isotropic in all directions. However, many organic semiconductor materials are one-dimensional systems with anisotropic carrier mobility when the molecules are properly aligned or stacked. In a molecularly aligned organic polymeric semiconductor film with linear extended π-conjugated backbone such as in the case of polyacetylenes, polythiophenes, the carrier mobility along the conjugated bone direction is about 2 to 3 orders of magnitude higher then the carrier mobility along the perpendicular to the conjugated backbone direction. In a stacked organic molecular semiconductor with localized π-conjugation system such as in the case of perylene, tetracene, copper phthalocyanine, the carrier mobility along the molecule stacking direction with π-electron overlap is also 2-3 orders of magnitude higher then the carrier mobility along the perpendicular to the molecule stacking direction.

The present invention makes use of the anisotropy in carrier mobility in an organized organic semiconductor by aligning molecules in the organic semiconductor material in the thin film of an organic TFT in such a direction that the carrier mobility from source to drain is several times to several orders of magnitude higher then the carrier mobility in all other directions.

To illustrate the concept of the present invention, six variations of organic TFT structures are presented in the following as examples.

Referring to FIG. 2, one embodiment of an organic TFT 20 in accordance with the present invention is illustrated. Organic TFT 20 includes a gate electrode 21 positioned on one surface of a layer of gate insulator material 22, which is composed of a dielectric medium. An orientation film 23 is positioned on the opposite surface of gate insulator material 22. A molecularly aligned organic semiconductor film 24 is positioned on the opposite surface of orientation film 23, and two laterally spaced apart conductive strips 25 and 26, as a source and a drain electrode, respectively, are positioned in laterally spaced apart relationship on the opposite surface of molecularly aligned organic semiconductor film 24.

Referring now to FIG. 3, another embodiment comprising an organic TFT 30 is illustrated. Organic TFT 30 includes a gate electrode 31 positioned on one surface of a gate insulator 32 (a layer of dielectric medium) that also serves as an orientation film. A film 34 of an aligned organic semiconductor material is positioned with one surface on, or in abutting engagement with, the opposite surface of gate insulator/orientation layer 32. Two laterally spaced apart conductive strips 35 and 36 are positioned on the opposite surface of film 34, as a source and a drain electrode, respectively.

Referring now to FIG. 4, still another embodiment comprising an organic TFT 40 is illustrated. Organic TFT 40 includes a gate electrode 41 positioned on one surface of a gate insulator 42 (a layer of dielectric medium). An orientation film 43 is positioned on (or in abutting engagement with) the opposite surface of layer 42. Two laterally spaced apart conductive strips 45 and 46 are positioned on the opposite surface of orientation film 43, as a source and a drain electrode, respectively. A film 44 of an organic semiconductor material is positioned on orientation film 43 so as to surround, or cover, conductive strips 45 and 46. Film 44 is molecularly aligned between conductive strips 45 and 46.

Referring now to FIG. 5, a further embodiment comprising an organic TFT 50 is illustrated. Organic TFT 50 includes a gate electrode 51 positioned on a gate insulator 52 (a layer of dielectric medium) that also serves as an orientation film. Two conductive strips 55 and 56 are positioned in laterally spaced apart relationship on the opposite surface of gate insulator/orientation film 52 as a source and a drain electrode. A film 54 of an organic semiconductor material is positioned over conductive strips 55 and 56 and gate insulator, orientation film 52 so as to be aligned between conductive strips 55 and 56.

Referring to FIG. 6, still a further embodiment comprising an organic TFT 60 is illustrated. Organic TFT 60 includes an orientation film 63 with two laterally spaced apart conductive strips 65 and 66 positioned on an upper surface thereof as a source and a drain electrode. A film 64 of an organic semiconductor material is positioned on the upper surface of orientation film 63 so as to be aligned between conductive strips 65 and 66 and cover conductive strips 65 and 66. A gate insulator 62 is positioned on the upper surface of film 64 and a gate electrode 61 is positioned on the upper surface of layer 62.

FIG. 7 illustrates still a further embodiment including an organic TFT 70. Organic TFT 70 is constituted of a layer of an orientation film 73 with a film 74 of an organic semiconductor aligned on top of orientation film 73. Two laterally spaced conductive strips 75 and 76 are positioned on the upper surface of film 74 as a source and a drain electrode. A layer of dielectric medium is deposited inbetween conductive strips 75 and 76 as a gate insulator 72, and a gate electrode 71 is positioned on the top of gate insulator 72.

In each of the above embodiments, the gate, source and drain electrodes are made of materials selected from stable metals, metal alloys, or transparent conductors such as indium tin oxide. The gate insulators (22, 32, 42, 52, 62, 72) are constructed from materials selected from inorganic dielectric media such as SiOx, SiNx and AlOx, as well as organic dielectric media such as polyimides, polyacrylates, poly(vinyl chloride), perfluoropolymers and liquid crystal polymers. Also, the orientation films (23, 32, 43, 52, 63, 73)

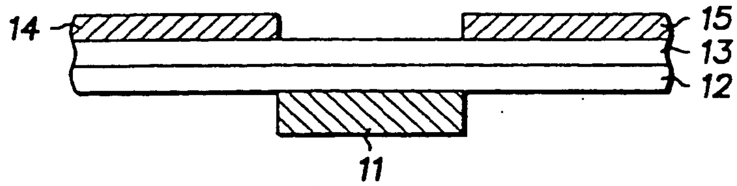

FIG. 1

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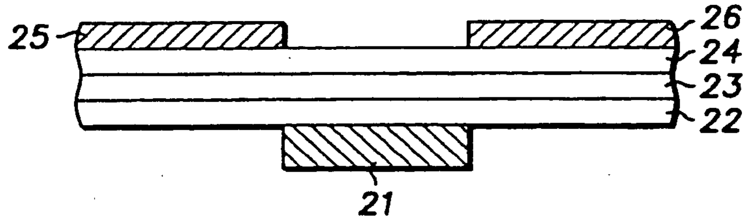

FIG. 2

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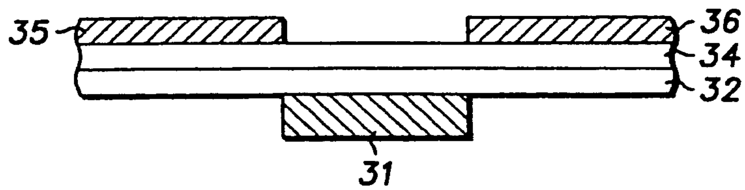

FIG. 3

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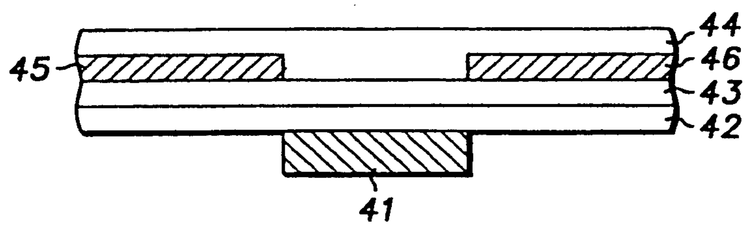

FIG. 4

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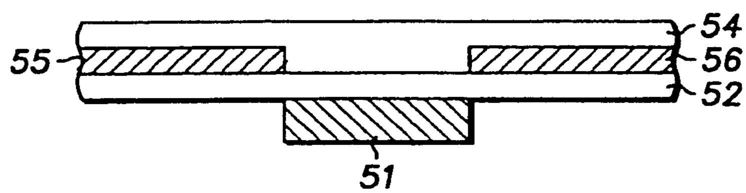

FIG. 5

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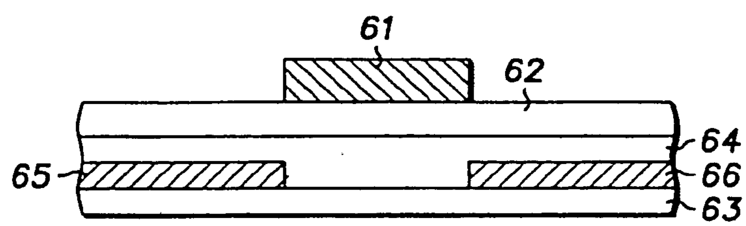

FIG. 6

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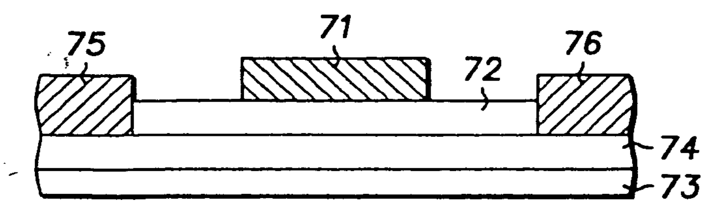

FIG. 7

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32, 42, 52, 62, 72) being operatively positioned adjacent to and in parallel with the film (24, 34, 44, 54, 64, 74) of organic semiconductor material; and

an orientation film (23, 32, 43, 52, 63, 73) positioned adjacent the film (24, 34, 44, 54, 64, 74) of organic semiconductor material so that molecular uniaxial alignment of the film (24, 34, 44, 54, 64, 74) of organic semiconductor material is achieved by the orientation film (23, 32, 43, 52, 63, 73) positioned adjacent the (24, 34, 44, 54, 64, 74) film of organic semiconductor material.

2. An organic thin film transistor as claimed in claim 1 wherein the organic semiconductor material (24, 34, 44, 54, 64, 74) includes organic polymeric semiconductor materials selected from conjugated hydrocarbon polymers such as polyacetylene, polydiacetylene, polyacene, polyphenylene, poly(phenylene vinylene), and the derivatives including oligomers of those conjugated hydrocarbon polymers; conjugated heterocyclic polymers such as polyaniline, polythiophene, polypyrrole, polyfuran, polypyridine, poly(thienylene vinylene) and alike, and the derivatives including oligomers of those conjugated heterocyclic polymers.

3. An organic thin film transistor as claimed in claim 1 wherein the orientation film (23, 32, 43, 52, 63, 73) is oriented such that the organic polymeric semiconductor material (24, 34, 44, 54, 64, 74) used in the transistor is positioned adjacent the orientation film (23, 32, 43, 52, 63, 73) with extended π-conjugated backbone aligned in a source (25, 35, 45, 55, 65, 75) to drain (26, 36, 46, 56, 66, 76) electrode direction.

4. An organic thin film transistor as claimed in claim 1 wherein the organic semiconductor material (24, 34, 44, 54, 64, 74) includes organic molecular semiconductor material selected from condensed aromatic hydrocarbons such as tetracene, chrysene, pentacene, pyrene, perylene, coronene, and the derivatives of those condensed aromatic hydrocarbons; metal complexes of porphine and phthalocyanine type of compounds such as zinc 1,20,15,20-tetraphenyl-21 H, 23 H-porphine, copper phthalocyanine, lutetium bisphthalocyanine, aluminum phthalocyanine chloride.

5. An organic thin film transistor as claimed in claim 1 wherein the orientation film (23, 32, 43, 52, 63, 73) is oriented such that the organic molecular semiconductor material (24, 34, 44, 54, 64, 74) is positioned adjacent the orientation film(23, 32, 43, 52, 63, 73) with the molecule stacking with π-electron overlapping aligned in a source (25, 35, 45, 55, 65, 75) to drain (26, 36, 46, 56, 66, 76) electrode direction.

6. An organic thin film transistor as claimed in claim 1 wherein the orientation film (23, 32, 43, 52, 63, 73) is oriented such that the organic semiconductor material (24, 34, 44, 54, 64, 74) aligned on the orientation film (23, 32, 43, 52, 63, 73) has the highest mobility in a source (25, 35, 45, 55, 65, 75) to drain (26, 36, 46, 56, 66, 76) electrode direction.

7. An organic thin film transistor as claimed in claim 1 wherein the orientation film (23, 32, 43, 52, 63, 73) is composed of materials selected from polyimides, perfluoropolymers, liquid crystal polymers.

8. An organic thin film transistor as claimed in claim 1 wherein the orientation film (23, 32, 43, 52, 63, 73) is included in the layer of gate insulator material.

9. A method of fabricating an organic thin film transistor comprising the steps of

forming a transistor body (20, 30, 40, 50, 60, 70) including a film (23, 32, 43, 52, 63, 73) of orientation material having uniaxially aligned molecules therein and a film of organic semiconductor material (24, 34, 44, 54, 64, 74) on the orientation film (23, 32, 43, 52, 63, 73) so that molecules of the organic semiconductor material (24, 34, 44, 54, 64, 74) are generally aligned with the molecules of the orientation film (23, 32, 43, 52, 63, 73); and

positioning a source electrode (25, 35, 45, 55, 65, 75) and a drain electrode (26, 36, 46, 56, 66, 76) in spaced apart relationship on the semiconductor body with the film of organic semiconductor material (24, 34, 44, 54, 64, 74) being positioned so that the uniaxially aligned molecules are aligned between the source (25, 35, 45, 55, 65, 75) and drain (26, 36, 46, 56, 66, 76) electrodes in a direction from the source (25, 35, 45, 55, 65, 75) to the drain (26, 36, 46, 56, 66, 76) electrodes; and

positioning a gate electrode (21, 31, 41, 51, 61, 71) on the transistor body.

10. A method of fabricating an organic thin film transistor as claimed in claim 9 wherein the molecules of the orientation film (23, 32, 43, 52, 63, 73) are oriented by one of the following methods: mechanically rubbing, electric field pulling, magnetic field pulling.

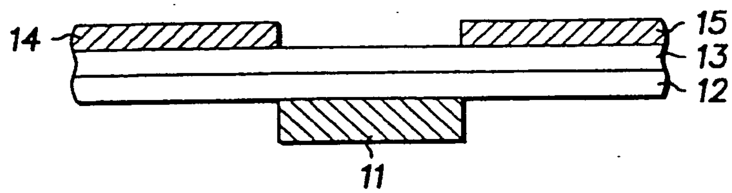

FIG. 1

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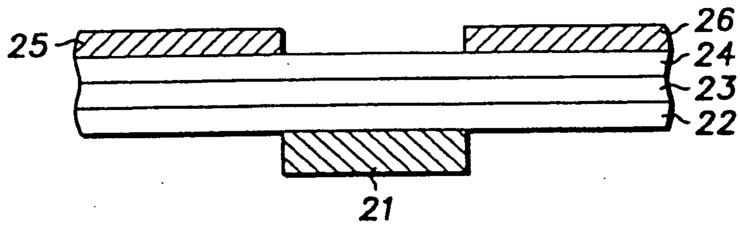

FIG. 2

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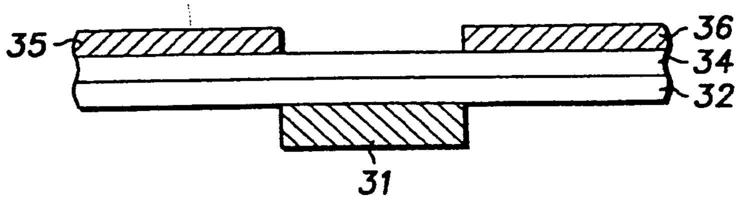

FIG. 3

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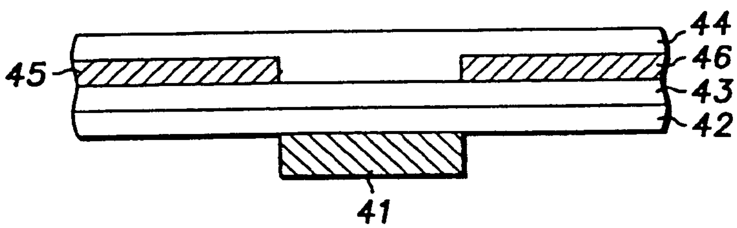

FIG. 4

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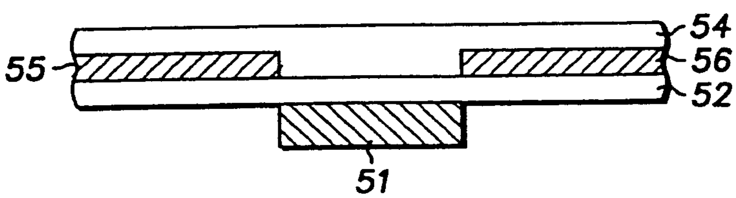

FIG. 5

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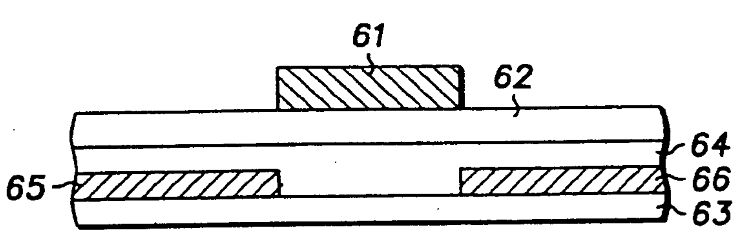

FIG. 6

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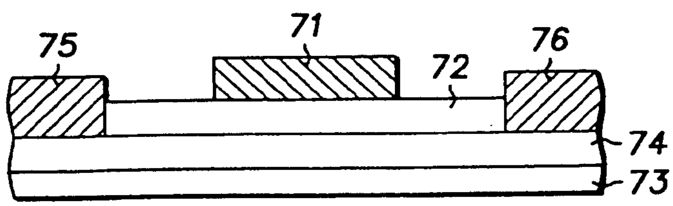

FIG. 7

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